A 524 GHZ POLARIMETRIC COMPACT RANGE FOR SCALE MODEL RCS MEASUREMENTS

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Abstract

A fully-polarimetric compact range operating at 524 GHz has been developed for obtaining Ka-band RCS measurements on 1:16th scale model targets. The transceiver consists of a fast switching, stepped, CW, X-band synthesizer driving dual X48 transmit multiplier chains and dual X48 local oscillator multiplier chains. Software range-gating is used to reject unwanted spurious responses in the compact range. A motorized target positioning system allows for fully automated sequencing of calibration and target measurements over a desired set of target aspect and depression angles. A flat disk and a dihedral at two seam orientations are used for both polarization and RCS calibration. Cross-polarization rejection ratios of better than 45 dB are routinely achieved. The compact range reflector consists of a 1.5m diameter aluminum reflector fed from the side to produce a 0.5m diameter quiet zone. Targets are measured in free-space or on a variety of ground planes designed to model most typical ground surfaces. A description of this 524 GHz compact range along with 3D ISAR measurement examples are presented in this paper.

Keywords: Compact Range; Scale Modeling, RCS Measurements, Submillimeter-Wave, Instrumentation; 3D ISAR.

1. Introduction

As radar technology continues to evolve, the availability of high quality, radar cross section (RCS) data is essential for successful development of radar capabilities such as automatic target recognition (ATR). The kind of data needed for these programs includes high-range-resolution (HRR) target profiles and synthetic aperture radar (SAR) images. Computer predictions and compact range measurements are often used to obtain this data when full-scale measurements are not practical, timely, or affordable. The Submillimeter-Wave Technology Laboratory (STL) at UMass Lowell has developed several compact ranges which specialize in using scaled frequencies to measure carefully scaled targets.

The technique of using scale models and scaled frequencies to study electromagnetic scattering dates back to the 1940s [1]. The use of submillimeter-wave radiation for scale model measurements was first reported in the late 1970s and early 1980s [2]. These early systems were based on narrow-band, optically pumped, submillimeter lasers which are still the best choice for frequencies above 700 GHz.

STL has refined these early laser-based systems into high-performance, compact ranges [3] capable of modeling the characteristics of most modern radar systems at most of the popular radar bands. The laser-based systems have been augmented with schottky diode sideband generators to provide a wide-band capability at THz frequencies. Scale factors used in these submillimeter systems range from 10:1 through 200:1, with frequencies extending up to 3 THz.

At frequencies below about 700 GHz, a completely solid-state approach using varactor multipliers is used. Here, a fast-switching, stepped CW, X-band source drives a series of cascaded doublers and/or triplers augmented with amplifiers where possible, to produce the desired transmit and LO signals. This solid-state approach offers a low maintenance and compact alternative to the laser-based systems. Currently, systems at 160 GHz [4], 524 GHz, and 660 GHz have been developed at STL using this approach.

The 524 GHz compact range is based on a fully polarimetric transceiver using a dual frequency, X-band, source driving four X48 multiplier chains. They are configured as a dual-channel linear-polarized transmit module and a dual-channel linear-polarized receiver. A custom IF converter/amplifier and DSP I-Q demodulator provide for a very low-noise receiver with high phase stability. The system operates in a high resolution, stepped CW mode typically measuring 2048 points over the sweep bandwidth. This high resolution sweep allows the entire measurement chamber to be resolved in range using software range gating techniques. In this way, spurious scattering from the chamber can be isolated and removed.

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In following sections, the details of the 524 GHz transceiver will be presented along with the design of the target positioning system and compact range into which it has been incorporated. In addition, ISAR and 3D ISAR data measured from a scale model target will be presented.

2. Compact Range

The 524 GHz compact range, shown in figure 1, consists of four major functional components; the transceiver, the collimating reflector, the target and calibration positioner, and the data acquisition system.

The transceiver produces about 200 μW of radiation tunable over 20 GHz and centered at 524 GHz. This radiation is coupled out of the transmitter's horn and lens as a 6° FWHM beam, which then propagates 6.3m out to the main compact range antenna mirror. The transmit beam at this point is about 0.68m in diameter. The radiation is collimated by this reflector and propagates downrange to the target located 10m from the reflector. Backscattered radiation from the target retraces the transmit path to the receive horn which has an identical beam pattern. Here the backscattered signal is down-converted through several stages to the final IF of 50 KHz where a DSP lockin amplifier measures its amplitude and phase. The combined transmit and receive patterns result in a 0.5m, 3 dB diameter quiet zone at the target.

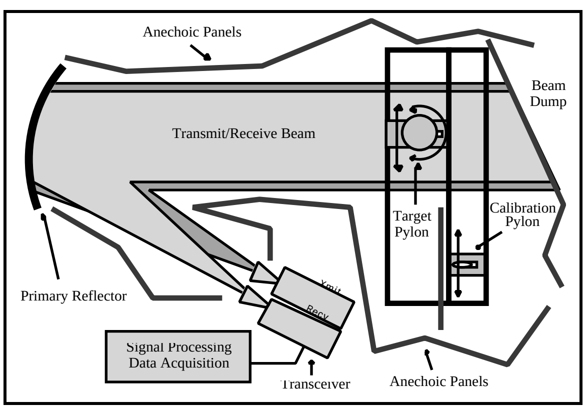

Figure 1. Top View of Compact Range.

The receive aperture is typically located adjacent to the transmit aperture resulting in a 0.3° bistatic system configuration. Reconfiguration of the system to monostatic operation is achieved with the addition of a 50/50 beam splitter, so that the optic axis of each feedhorn intersects and becomes collinear at the beam splitter.

The compact range antenna is a 1.5m diameter, 6.3m focal length, CNC machined, hand polished, aluminum mirror. The mirror edge is rolled to minimize diffracted radiation. The mirror has an optical finish which greatly aids in the alignment of the system as well as testing of the antenna using optical techniques. The mirror is supported on an adjustable mount allowing fine changes in height and orientation.

The target positioner automates the measurement and calibration operations. The positioner allows for the translation of the calibration or target pylons into and out of the beam. The target pylon positions the target in azimuth and elevation. The calibration pylon is used to mount the ogive terminated flat plate and dihedral calibration objects. The dihedral can be rotated to any seam orientation via a high-resolution stepping motor equipped with an optical encoder.

The entire compact range chamber is covered with a custom fabricated, wedge-style, anechoic material [5] designed at UMass STL and optimized for 524 GHz operation. The anechoic is mounted onto large movable panels which allows the angle of the anechoic to be optimized to reduce backscatter, minimize target-chamber interactions and to deflect unwanted radiation to appropriate areas of the chamber.

All target positioning and transceiver operations are controlled via the Macintosh-based data acquisition system. All data acquisition and processing software are written in National Instrument's "Labview"® graphical programming software. Data processing allows data to be presented as TRCS plots, HRR profiles, and ISAR images.

3. Transceiver

The transceiver consists of six modules; the frequency synthesizer/converter, the transmit multiplier chain, the receive multiplier chain/mixer, the IF converter, the I/Q demodulator, and data acquisition. A diagram of these modules is presented in figure 2.

The frequency synthesizer/converter module generates three principal frequencies; the transmit multiplier chain drive signal (10.7-11.12 GHz), the receive multiplier chain drive signal (10.6-11.06 GHz), and the IF frequency/phase reference (3 GHz). Because of the X48 multiplication factor, very good spectral purity is extremely important. To achieve these frequencies, the 10.83 GHz synthesizer center frequency is shifted up by 62.5 MHz (3.0 GHz/48). This difference, after X48 multiplication, results ultimately in the 3 GHz IF at the receiver. The 62.5 MHz is also multiplied by X48 to generate a 3 GHz reference which is down-converted in the IF chain along with the horizontal and vertical receive signals.

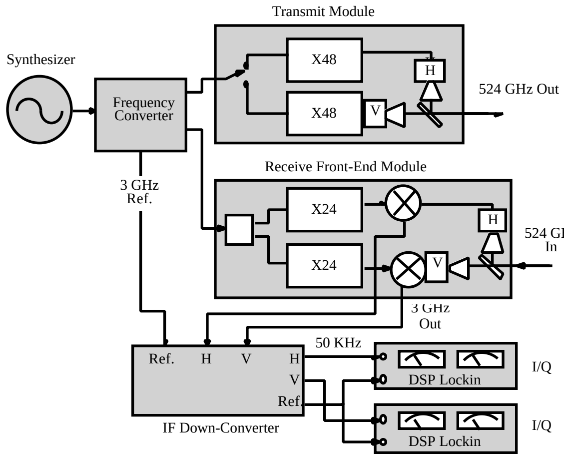

Figure 2. Block diagram of 524 GHz Transceiver

The multiplier chains are configured as a transmit module and a receive module as shown in figures 2,3 and 4. The transmit multiplier chain consists of an amplified quadrupler followed by two additional varactor doublers and a tripler to achieve the desired 524 GHz center frequency. Each final tripler has an integral diagonal horn which radiates a 12°, 3 dB beam. A small lens located very near the horn's aperture reduces the beam angle to 6°. The horizontal and vertical beams, directed 90° with respect to each other, radiate toward opposite faces of a common 45° orientation wire-grid where the two beams are combined. The composite 6° beam continues on towards a small flat steering mirror which directs the beam out towards the collimating antenna Only one transmit chain is active at a time, generating greater than 200 µW of output power at either horizontal or vertical polarization. The wire grid cleans up the polarization reducing any cross-polarization components to >35 dB below the co-pol channel.

The receiver uses two additional multiplier chains to generate the LOs for the two primary schottky mixers. In most respects, the receiver module is identical in configuration to the transmitter. The received 524 GHz signal is split in a receiver wire-grid and coupled through separate lenses and integral horns in the schottky mixers and down-converted to a pair of 3 GHz IF signals. The receiver NEP is about 4×10^{-19} W/Hz. The horizontal, vertical and reference IF signals are amplified and further down-converted to 50 KHz. Two Stanford Research SR-830 digital signal processing (DSP) lockin amplifiers (phase-lock demodulators) are used to recover the I&Q signals from the three 50 KHz signals. The DSP technique results in no significant DC offsets or quadrature errors. The I&Q voltages are then digitized in a 4 channel, 16 bit A-D converter and stored for subsequent processing.

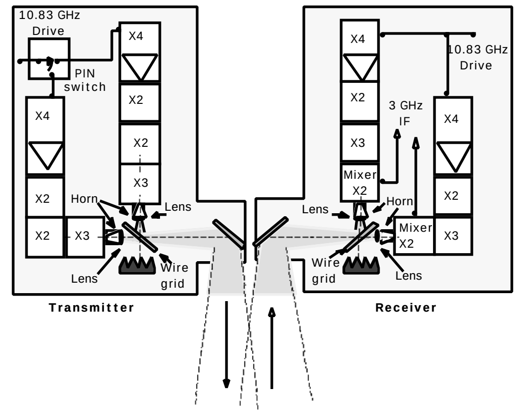

Figure 3. Diagram of 524 multiplier chain modules.

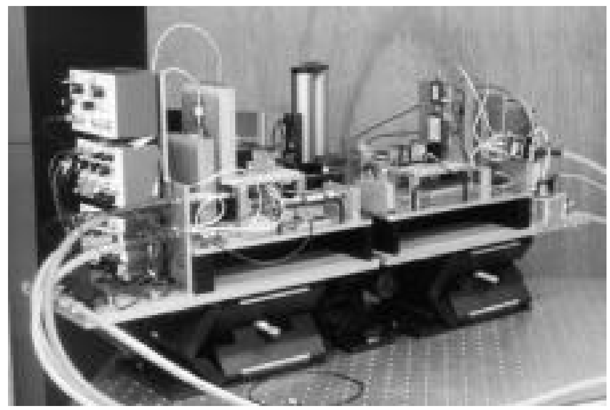

Figure 4. Rear view of receive (right), and transmit (left) modules.

4. Software Range Gating

One of the major concerns with any RCS measurement system is the isolation of the target return from unwanted spurious signals. These signals include: leakage in the transceiver, coupling between the feed horns, stray scattering from features in the chamber, or interactions between the target and the chamber. In a pulsed system, signals can be accepted or rejected according to time gates used to activate the receivers only when valid reflections are expected. Unfortunately, narrow time gates can introduce significant return losses which are unacceptable when trying to maximize sensitivity with a low power transmitter.

In a stepped CW system, a software range gating scheme can be implemented by Fourier transforming the measured complex sweep data from the frequency domain into the time domain. The time gate corresponding to the target is then windowed, removing unwanted chamber responses. Unwanted signals can usually be rejected by better than 40 dB, depending on phase stability and system noise. Since the range per bin is about 8mm, 2048 steps per sweep results in about 15m of unambiguous distance in the chamber.

Since the distance from the transceiver to the target is about 14m, this works out well. If there is any aliasing, it usually does not fall within the target bins. Examples of a typical profile within a range are presented in [4].

5. Calibration

Calibration is accomplished with a set of precision machined reflectors which are measured sequentially before each run. The calibration objects consist of a flat disk and a dihedral. The cross-sectional area of the calibration objects is chosen to be within 10 to 20 dB of the maximum target RCS anticipated. This allows for a good signal-to-noise and signal-to-clutter ratio for the calibration voltages, producing a clean RCS and polarization calibration. Typically, calibration objects have Ka-band RCS values of between 10 and 30 dBsm.

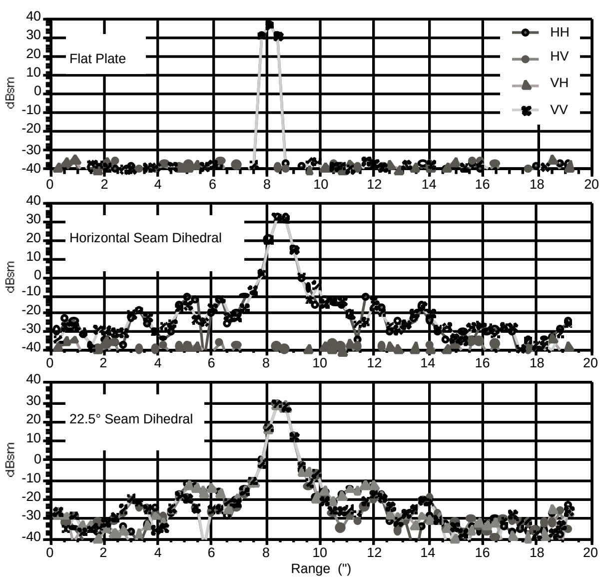

Figure 5. Polarimetric range profiles of three different calibration object measurements: a flat disk (top) a horizontal seam dihedral (center), and a 22.5° seam dihedral.

A typical calibration sequence consists of the measurement of a flat disk and multiple measurements of a dihedral with its seam oriented at 0° (vertical), 22.5°, 45°, 90° (horizontal), and finally a background measurement (cal object and target pylon translated out of the beam.) A measurement consists of a complete frequency sweep, measuring phase and amplitude at each frequency, for each of the four linear polarization states (HH, HV, VH, VV). The background is subtracted from each of the calibration object measurements and the data is used to calculate the polarization and RCS correction matrix.

Polarization calibration is obtained using a very robust technique described by Chen et al. [6]. Only three measurements are used for the calculation (a disk and dihedral at 90° and 67.5°). Measurements at other orientations of the dihedral are used only to check the performance of the correction matrices. The cross-pol rejection ratio is improved, from about 30 dB before software calibration, to between 45 and 60 dB afterwards. An example of the calibrated flat disk and dihedral is presented in figure 5 showing a very good cross-pol rejection ratios. The broad bases of the peaks in the measurements are due to phase noise introduced by motion between the transmitter, mirror, and target caused by the current location of this compact range on an unstable upper-level floor. Relocation to a low-vibration, ground-floor facility is anticipated in the near future.

6. Target Positioner

The target positioner, shown with anechoic shielding removed from base in figure 6, is an automated positioning system that serves two major functions: target and calibration object support and orientation, and target and calibration pylon insertion and removal. The basic support for targets and calibration objects is the low-RCS pylon. The pylons consist of a 1.2m long aluminum pylon with an ogive cross section. The pylon is raked back a minimum of 10° to reduce back scatter.

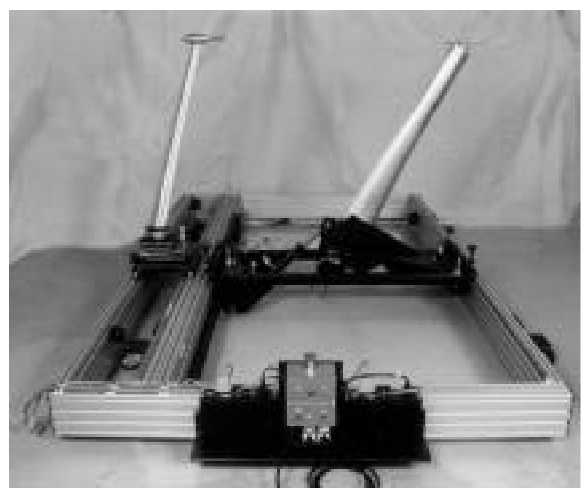

Figure 6. Side view of the target positioning system with calibration pylon at the rear (left) and the target pylon with adjustable depression at the front (right). Both are mounted on motorized translation stages.

The target aspect position is controlled from a rotary stage mounted below the target pylon and connected to it with a drive shaft enclosed within the pylon.. Accurate positioning in azimuth of 0.005° is necessary to allow high-quality ISAR imagery to be processed from the measurement data. The entire pylon can be tilted at the base a total of 20°. To achieve a full 80° of travel in elevation, a set of pylon heads biased at -5°, 15°, 35°, and 55° can be interchanged as required to provide from -5° to 80°. A fifth pylon head could be fabricated if elevation angles close to 90° are desired.

When measurements of a target on a groundplane (figure 7) are desired, a special motorized head is retrofitted to the pylon top. This head supports a 1m diameter groundplane. Groundplanes with varying roughness and dielectric properties can be used to simulate almost any surface from concrete to sand. Because the ground plane is relatively small, the elevation angles used should be steep enough to allow the image of the target in the groundplane to be visible.

7. Measurements

Data measured using the scale models in the range are typically processed into TRCS plots and ISAR images. Examples of this kind of data were presented in [4]. Since the system is very stable, a sequence of ISAR images taken at different depression angles can be further processed into 3D ISAR. Although the depression pylon on this system was not designed with the precision required for this kind of processing, excellent 3D images were generated with the aid of a phase correction algorithm.

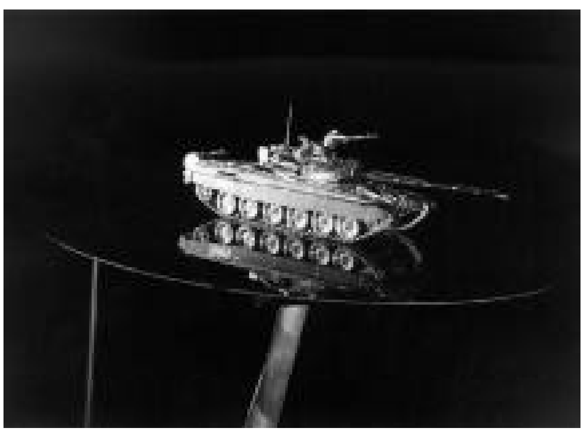

Figure 7. View of the scale-model tank shown mounted on a smooth groundplane

To obtain 3D measurements, a scale model target similar to the one shown in figure 7 was mounted on the groundplane. To aid in phase correction, a trihedral was positioned to the front and right of the model. The target was measured from –6.0° to +6.0 degrees in 0.015° increments. The bandwidth was set to 11 GHz.

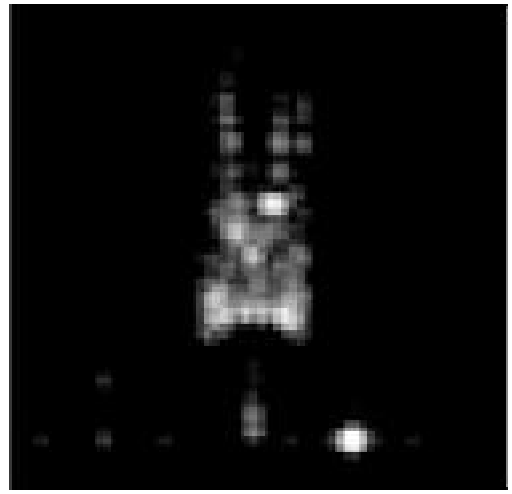

Figure 8. Incoherent sum of the 64 ISAR images measured from 4.5°- 5.5° in 0.015° increments.

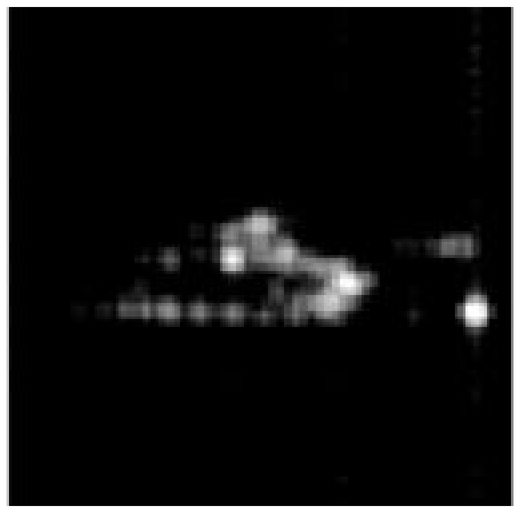

Figure 9. Side view created from processing the above ISAR images down along range slices.

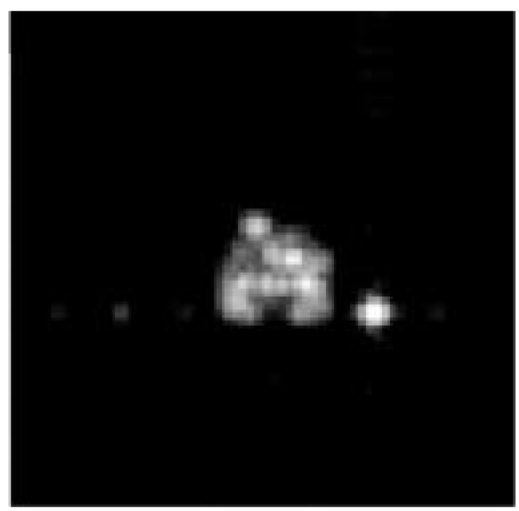

Figure 10. Front view created from processing above ISAR images down along cross-range slices.

After each aspect sweep, the target depression was increased by 0.015°. The depression sweeps extended from 5.5° to 6.5° for this example. For a typical measurement, a much larger range of aspect and depression angles would be acquired creating a broad array from which a large choice of images could be generated.

Since the depression axis center of rotation is at the bottom of the pylon, the target experiences significant translation in the range direction as the angle is changed. The first step in processing the data is to compensate for this translation. The geometry of the depression axis was modeled and the average range excursion at each depression angle calculated If this correction is sucessful, the in-scene trihedral will remain in the same range bin for all depression angles.

The second correction involves monitoring the residual change in phase of the trihedral as a function of depression angle. Since the precision of the pylon's depression axis is not adequate for clean ISAR image generation, the slope of the phase in the trihderal bin is extracted and fit to a line and a secondary correction is determined and applied to the data. The data is reprocessed with this correction. The results of a model target processed using this technique is shown in figures 8, 9, and 10,

The 64x64x64 data array is processed using a Hanning window and a 3D Fourier transform. The resulting 3D cube viewed from the top generates the composite (normalized incoherent sum) ISAR image of figure 8. The composite side view is presented in figure 9, and the composite front view is presented in figure 10. Any slice through the target can also be displayed .

The 3D ISAR image volume can then be processed to determine a set of scattering centers with XYZ coordinates. This type of 3D data can be useful input for seeker simulations where scattered waveforms can be synthesized to study seeker servo loop behavior when approaching a target.

8. Conclusion

A fully polarimetric compact range based on an Ka-band source driving X48 multiplier chains to produce radiation at 524 GHz has been described. The system uses software range gating and calibration techniques to achieve a clean target profile with cross-pol rejection ratios of >45 dB. Capabilities for both free-space and ground-plane measurements have been described. A fully automated positioning and calibration system allows unattended range operation 24 hours a day.

3D ISAR images processed from the scale-model data were presented showing the precision and capability of the system. Because small models are inexpensive to fabricate and the space requirements for this type of range are modest, submillimeter compact ranges are proving to be a cost effective, viable complement to full-scale systems and computer codes.

REFERENCES

[1] G. Sinclair, "Theory of Models of Electromagnetic Systems" *Proc. IRE*, Vol. 36, No. 11, Nov. 1948, pp.1364-1370.

[2] J. Waldman, et al., "Submillimeter Model Measurements and their Application to Millimeter Radar Systems," *Fourth Int. Conf. on Infrared and Millimeter Waves and Their Applications*, Miami Beach, FL. December 10-15, 1979, pp. 49-50.

[3] M. J. Coulombe et al., "A 585 Ghz Compact Range for Scale Model RCS Measurements" *Proc. of the Antenna Measurements and Techniques Association*, Dallas TX 1993, pp 129-134

[4] M. J. Coulombe et al., "A 160 Ghz Compact Range for Scale Model RCS Measurements" *Proc. of the Antenna Measurements and Techniques Association*, Dallas TX 1996, pp 239-244

[5] R. H. Giles et al., "Tailoring Artificial Dielectric Materials at Terahertz Frequencies", *Proc. of Fourth Int. Symp. of Space THz Technology*, Los Angeles, CA, 1993

[6] T.J. Chen et al., "A New Calibration Algorithm of Wide-Band Polarimetric Measurement System", *IEEE Trans. of Antennas and Propagation*, Vol. 39, No. 8, August 1991

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